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Algae as an Indicator of Water Quality

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Abstract

The formation of plankton/algae under natural conditions is related to tolerance class (ecological optimum) due to abiotic limiting factors of ecosystem, as well as the biotic interactions among algae. In the ecological niche, the appearance of organisms is affected by anthropogenic and non-anthropogenic environmental factors. Algae composition and temporal variation in abundances are important in determining the trophic level of lakes. Algal communities are sensitive to changes in their habitat, and thus, total biomass of algae and many algae species are used as indicators of water quality. Algae communities give more knowledge on variations in water quality than nutrient or chlorophyll-a values. Water quality is a canonical group of physical, chemical, and biological properties of the given water. Consequently, eutrophication of freshwater is regarded as a water quality which results in the degeneration of the aquatic ecosystem and affects water utilisation. Cyanobacteria has been accepted as a major indicator of eutrophication in freshwater as their blooms are common in waters affected by nutrient concentration. The purpose of this chapter is to assess physical and chemical variables and the role of algal abundance to determine the water quality in the freshwater ecosystems.

Keywords: algae, biomonitoring, indicator, nutrients, spatial-temporal variation, water quality

1. Introduction

Algae are a significant component of biological monitoring programs for assessing water quality. They are eligible to water quality assessment because of their nutrient requirements, rapid reproduction rate and very short life cycle. Algae are important indicators of environment situation since they respond immediately to both qualitative and quantitative composition of species in a wide range of water situations due to alters in water chemistry such as increases in

water pollution based on domestic/industrial wastes and affect the composition of genera that are able to tolerate these situations.

From an ecological and public health perspective; the abundance of nutrients-containing nitrogen (N) and phosphorus (P) that flow into lakes, reservoirs, and the other aquatic ecosystems resulting in eutrophication is of great importance. The N:P ratio identifies which alga genera are dominant, present or absent in these nutrient impacted aquatic ecosystems [1]. Sources of inorganic compounds that contain these elements involve domestic detergents, commercial fertilizers used for agriculture, and runoff along with organic pollution from sewage and livestock waste.

Biological analyses can define possible changes in water quality, as well as the tendencies with times that are reflected in environment variations and the composition of aquatic organisms. Phytoplankton consists of a large diversity of algae with different forms and life history strategies to increase productivity; planktonic genera such as *Microcystis*, *Anabaena*, *Nodularia*, *Planktothrix*, *Aphanizomenon*, *Cylindrospermopsis*, *Trichodesmium*, which have gas vacuoles that help to float, or benthic species (*Lyngbya*, *Phormidium*, *Oscillatoria*, *Schizothrix*) that tend to locate at the sediment [2], and neutrally buoyant algae having a similar density to water such as *Oocystis* and *Chlorella* and species of Dinoflagellates and Euglenophyta migrating freely in the water column [3].

When reservoirs and lakes become more eutrophicated, the diversity of phytoplankton species gradually declines, which leads eventually to Cyanobacteria dominance and toxin production [4].

Phytoplankton communities are sensitive to alterations in their habitats, and thereby, phytoplankton total biomass and many phytoplankton species are utilized as indicators of aquatic habitat qualifications [3, 4]. Phytoplankton/algal communities give more evidences concerning alterations in water quality than nutrient or chlorophyll-a concentration. Water quality is a whole of physical, chemical, and biological properties of the water [5].

It is important to consider that the phytoplankton community changes quickly as a response to changes in water quality. The first reaction on such changes in the water environment is a quantitative change of the phytoplankton community. The amount of algae increases or decreases depending on the type of impacts on the water mass, which is followed by qualitative changes of the phytoplankton community. New species colonize in the lakes and some of the original species may decrease in importance based on local extinction in some cases.

2. Bioindicator systems

According to in Ref. [6], the Baas–Becking hypothesis [7], which explains that ‘everything is everywhere—the environment selects’, has dominated the view on microbial distribution for decades and has definitely conducted to the prevailing concept that algae are cosmopolitan organisms. While physical and chemical water quality measurements can indicate the level of water degradation, these methods represent only a “snapshot” of the current conditions in

aquatic systems by giving only a transient picture of prevailing environmental conditions. The abundance and community patterns of organisms “*in-situ*” reflect precisely the water quality at any point. Organisms can be used to compare relative variations in water quality in terms habitat variability or time [8–12].

Water quality parameters (particular and dissolved nutrients concentrations, suspended solids and/or turbidity, and chlorophyll-a as phytoplankton biomass) are usually detected directly, either by traditional periodical water sample collection and following analysis, or with continuously logging instruments (available for turbidity and chlorophyll) [8]. However, the dilemma is that periodical measurements of parameters that vary significantly with time frames less than the sampling interval will require long time series to detect any change; whereas, continuously logging instruments are expensive to purchase and require regular field working for maintenance. Moreover, as our understanding of relationships between habitat situations and biological communities remains poor, it can be difficult to explain the ecological relevance of detected variability in water quality. For these reasons, numerous studies have proposed to use bioindicators for evaluating changes in water quality, testing various measures of lakes and rivers, and assessing biological organisms [13].

It is important that bioindicators amalgamate ecological conditions over time. The changes in any environmental condition cause variation of bioindicator groups. Theoretically, a bioindicator system should combine a number of specific measures that vary in their effect ranges and response times to altering water quality [14] and which can be quantified during intermittent visits once reference point levels are established. The Ref. [15] defines the term bioindicators as characteristic species or communities, which, by their presence, give information about the surrounding physicochemical properties of ecosystem (water quality) at a specific site.

2.1. Why are bioindicators better than the other methods?

Bioindicators comprise biological processes, species, and communities and are used to assess water quality of the ecosystem and how the water quality alters with time. Variations in the ecosystem are often related to anthropogenic effects or natural stressors. Finally, the use of bioindicators caused a drastic change in classic measure of their ecosystem quality and offers great benefits:

1. Bioindicators add a periodical component corresponding to the life span or residence time of an organism in a specific system by allowing the integration of current, past or future habitat situations. Unfortunately, many physicochemical analyses describe only situations at the time of sampling but have an increasing probability of missing inadvertently pulses of pollutants. Furthermore, contaminants can occur at very low concentrations. On the other hand, the tolerance range of bioindicators obtains a frame of biologically significant pollutant values, no matter how small.
2. Bioindicator indicates indirect biological impacts of pollutants when physicochemical analysis cannot indicate (phosphorus concentration effects on phytoplankton population). Therewith, chemical measurements may not precisely demonstrate a declining in

species diversity or how the growth and reproduction of other species may decline depend on competitive exception.

3. Indirect contaminant effects are complex to explain from chemical and physical analysis in case of bioaccumulation. Other contaminants such as metal accumulate in organisms are found at concentrations to amplify through food webs. Therefore, contaminant values at higher trophic levels may be insufficient to describe physical and chemical analysis.
4. While the use of whole communities (all species' responses within them) can be informative, problems can arise in especially speciose habitats. Moreover, a bioindication signal can be unclear by an excessive number of divergent species' responses (some species may increase while others decrease). This narrowed approach makes monitoring more biologically relevant and cost-effective.

Also, a general dilemma about physicochemical analysis is that they simplify a complicated indigenous response in these species-rich habitats. Due to complexities of environments bioindicators use a representative or collected response to transmit a dynamic condition of the environments.

Communities of algae living in the water bodies provide evidences of the environmental history of the water in two ways: firstly, by differential sensitivities and recovery rates of species to substances in the water; and secondly, by concentration and accumulation of substances in their cells [16].

Algae are known to have very specific requirements for growth and reproduction, and the presence of a characteristic species in a habitat remarks that the given determinant is within the tolerance limits of that species. It is in the sense that the term 'bioindicator' is used.

On the other hand, not all biotic processes, species or communities can serve as successful bioindicators. Physicochemical and biological factors such as substrate, light, temperature, competition vary among habitats. With time, populations develop strategies to maximize growth and reproduction within a specific range of habitat conditions [17]. Bioindicator species indicate effectively the environmental situation cause of their moderate tolerance to fluctuation of ecosystem properties [18–20].

In contrast, rare species (or species assemblages) with narrow tolerances are often too sensitive to habitat alterations, or too sporadically encountered, to demonstrate the general biological response. Bioindicators possess a moderate tolerance to ecosystem variability compared to rare and cosmopolite species. This tolerance affords them sensitivity to indicate ecosystem alterations, yet endurance to withstand some variabilities and show the general biological response.

Bioindicator species differ from key indicator species, while both are useful in revealing information about their habitats. Bioindicators explain the characteristic of habitat through their population abundance of particular responses to the ecosystem. Key indicator species are those species that are essential to an environment. If such species were to disappear, an important of the food web will disappear or undergo shifts in dominant species.

On the other side, the utilization of bioindicators is not just restricted to a single species with a limited ecological tolerance. Entire communities, involving a wide range of ecological tolerances, can serve as bioindicators and represent multiple sources of data to assess ecosystem situation in a “biotic index” or “multimetric” approach.

3. Water quality monitoring

The studies using phytoplankton and algae for water quality monitoring have revealed that alteration in composition demonstrates not only variations in water quality, but also alterations in physical parameters and biotic relationships. The Ref. [21] asserts that differences in water chemistry may change relative proportions of a few dominant taxa but often have a little effect on general species composition. and growth rates of species taxonomically change under influence of factors regulating composition of algae and population structure, which is closely regulated with water quality.

Algae were indicated as a beneficial tool for evaluating long-term alters in ecosystem such as those related to eutrophication, water management, alters in land use at the scale of watershed, and climate changes. In this sense, algae appear a useful biological indicator because they respond rapidly to alterations in ecosystem situations, thus enabling a quick assessment of water quality [21].

In general utilization, the terms “biomonitoring” and “bioindication” are substitutable; on the other hand, in the scientific sense, these terms have more specific meanings. Bioindicators qualitatively evaluate biological responses to ecological stress (abundance of algal species), while biomonitors quantitatively define a response (reductions in algal chlorophyll content or diversity indicates the presence and severity of water pollution). The term “bioindicator” is used as a unique term to refer to all terms related to the detection of biotic responses to ecological limiting factors. There are some major monitor roles of bioindicators:

1. The ecosystem qualification (physical and/or chemical fluctuations).
2. Ecological processes.
3. Biodiversity [22].

Chemical analysis of water quality such as inorganic nutrients, organic/inorganic pollutants and salinity is descriptive. However, conducting continuous analysis is not useful due to the associated time and particularly cost limitations. Nevertheless, biological measures can show all aspects of water quality with time and give a direct measure of the ecological impact of ecosystem variables. Biomonitoring allows a reliable relatively low-cost way to record conditions over a number of sites [15].

The following properties of the algae make it better suited to biomonitoring than the other biota [16, 23]:

- The algae are autotrophic and placed at the interface between the habitat and biotic components of the food web.

- The algae are mainly sessile; they cannot migrate to avoid pollution so must tolerate or disappear.
- Algal communities are species-rich and each species has its own tolerances.
- All algae have short life cycles and so have a rapid response to change, while the community lives long enough to integrate impacts with time.
- The algae are spatially dense and easy to sample and store.
- The algae are smaller in size than other biota and so are potentially more sensitive to pollution at lower concentrations.

4. Phytoplankton/algal ecology in lake and reservoir management

A vital key to the management of water bodies has been the development of models linking nutrient loading to the reduction of algal biomass to levels acceptable for a particular usage [24]. While phosphorus is described as limiting in most temperate lakes, nitrogen plays a crucial role in forming phytoplankton communities in tropical aquatic ecosystems [25].

Assessments related to phytoplankton are required to involve taxonomic composition, abundance, biomass, and plankton blooms for the ecological classification of waters [26, 27]. Phytoplankton succession and community composition demonstrate habitat situations of the ecosystem and nutrient availability acts an important role [28–30] in structuring that community. Given suitable habitat situations, the main biotic response to nutrient enrichment in aquatic ecosystems is the growth of phytoplankton and aquatic macrophyte.

Algae, in particular phytoplankton, play a fundamental role in lake and reservoir ecosystems, where nutrients are known to limit primary productivity rates. Populations in water bodies reflect the quality of water and affect community structure, biomass and productivity rates [31, 32]. Studies conducted on the relationships between algae and its fluctuating environment have resulted in an understanding of the main driving forces behind temporal and spatial patterns of its existence.

Desmids, Chrysophyceae and diatoms of the genera *Tabellaria* and *Cyclotella* peculiarize the infrequent but diverse plankton of the oligotrophic Caledonian-type lakes; Cyanobacteria (*Anabaena*, *Aphanizomenon*, *Microcystis*) and the diatoms *Asterionella*, *Aulacoseira*, *Fragilaria* and *Stephanodiscus* are demonstrative for more eutrophic levels [33]. Diatoms, Chlorophytes and Cyanobacteria occur right across the width of the spectrum by embracing from ultra-oligotrophy to hyper-eutrophy. Desmids, centric diatoms, even the Chrysophyceae, occupy substantial horizontal blocks. As in single orders, such as, the Oscillatoriales, and the same ostensive genera such as *Planktothrix*, *P. rubescens* has dominance in deep, mesotrophic alpine lakes; and, to *P. agardhii* has dominance in shallow basins in case of increasing nutrient content. Generally, *Chlorella*, *Scenedesmus*, *Ankistrodesmus* and Euglenoids are found in the nutrient-rich and eutrophic lakes. While *Ceratium*, *Microcystis*, *Aulacoseira granulate* in summer in the eutrophic lakes, *Cyclotella* spp. and *Aulacoseira subarctica* in the mesotrophic temperate

lakes in spring or *Dinobryon*, *Uroglena*, *Gemellcystis* and *Sphaerocystis* in the oligotrophic lakes have high abundance.

The abiding challenge is to explain *why* the algae should be distributed in this way. The trophic status of a habitat is dependent on community succession of some species. Phytoplankton succession follows R-C-S strategies both in natural and experimental situations [34]. Experiments completed in mesocosms revealed that the initial community primarily represented by R- and S-strategists (*Planktothrix*, *Cylindrospermopsis* and *Microcystis*) was gradually substituted by C-strategists *Cryptomonas* spp. Chlorococcales in general [35]. The Ref. [4] indicated that the Cyanobacteria, *Planktothrix* overwhelmingly dominated during the dry period and was succeeded by the colonial Cyanobacteria, *Microcystis aeruginosa* in the wet period and the members of Chlorococcales simply co-existed along with these dominant species of Cyanobacteria.

The potential ecological complications of nutrient fortification and disturbance also comprise modifications of the natural phytoplankton community composition, which may in turn alter ecosystem food web and nutrient cycling [17, 36]. If the growth of more readily grazed phytoplankton groups such as diatoms is favored, trophic transfer and nutrient cycling will occur widely in aquatic ecosystem, with enlarged export of the assimilated algae to lake ecosystems. On the other hand, if the nutrient loading favors the phytoplankton functional groups, which may not be readily grazed, such as Dinoflagellates, trophic transfer will be poor and relatively large amounts of unconsumed algal biomass will eventually be found in the sediment.

The Refs. [37, 38] reported that the collected seasonal epipelagic diatom samples were correlated with a combination of environmental variables such as temperature, the concentrations of nitrite, and percentage of total organic carbon in the sediment.

The growth rate of phytoplankton hinges on bioavailable phosphorus and nitrogen values in water, light intensity and half saturation constants of nutrients, and light in compliance with the Michaelis–Menten function [39].

On the other hand, in the growth rate, the limitations of each nutrient and light are multiplied instead of the usual way to take the minimum of the three limiting factors. Thus, the growth rate hinges on availability of both nutrients and light at the same time, not just on the minimum factor. Expressed in this way the growth rate is not as sensitive to the limiting factor and inexactness in nutrient relations (**Figure 1**). The nutrient level that can be utilized by algae is calculated by subtracting the nutrients in algae and detritus from the total nutrient value [39].

Before beginning a discussion on plankton indicators, it may be preferable to indicate that some clutters have resulted from two different approaches. On the one side, attempts have been made to characterize plankton by the number of species, regardless of whether these species are presented by few or many individuals. On the other side, we have the search for ecological dominants and concurrent attempts to classify and name communities or associations by their dominant species. Therefore, the plankton of an oligotrophic lake is represented by desmids, which means that it includes many species of desmids but the plankton sample may be dominated by diatoms. This is a very general condition in oligotrophic lakes.

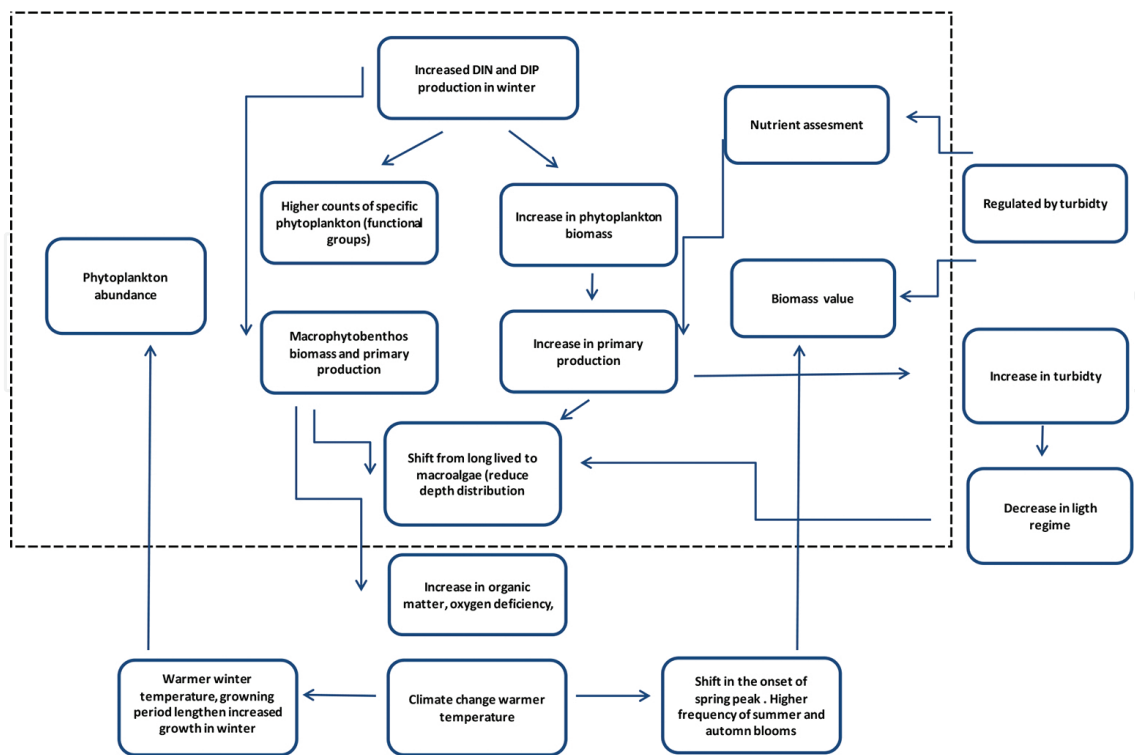


Figure 1. Diagram of the phytoplankton responses to changing nutrient and environmental conditions (according to [36]).

Multivariate methods such as classification and ordination have been used to explore cooperation among ecological factors or sites and to reveal the significance of hierarchy of their variability. These methods aid in making ecological clarification of field data and in creating new hypotheses [31, 40].

5. Indicator values of the algal groups

In general, the water quality is recognized and detected by several physical, chemical, and biotic procedures. The biotic analysis (qualitative and quantitative analyses of phytoplankton communities) is performed in support of the interpretation of the results gained from physical and chemical analysis of the water. The monitoring of phytoplankton and algae is of great significance because the monitoring based solely on physical and chemical analysis is sometimes insufficient. The phytoplankton composition not only demonstrates the certain situation of the waters but also the previous situations of aquatic ecosystem. Phytoplankton demonstrates water quality through changes in its community composition, and distribution, and proportion of sensitive species [41].

Species rarity is of specific significance in total structure of species diversity. Rare species constitute an important component of species richness and are a focus of many ecological theories and disputations [41, 42]. If rare species constitute the largest component of species

richness, they may act an important role as a ‘safety net’ for community conservation and diversity [42]. Species diversity diminishes to minimum levels when one or a few species are dominant.

The Ref. [36] showed that a number of indicators of nutrient improvement are briefed below. These indicators related to indicators of direct effects:

- Too much growth of phytoplankton in the aquatic ecosystem.
- Perturbation in specific plankton community.
- Too much growth of opportunistic macroalgae on intertidal sediments and rock.
- Too much growth of epiphytic algae, particularly on macrophyte.

Indicators of undirected effects include:

- Oxygen depletion in the water gradually increases. After this effect, phytoplankton blooms start to disappear. This could have lethal and sub-lethal effects on fish and invertebrates.
- Increased turbidity in the water bodies causing to decrease photic zone and shading out macrophytes.
- Reduction of oxygen in surface sediment causing to anoxia. This could have lethal influences on invertebrates which would also effect birds feeding on them.

Chlorophyll-a values characterize a very simple and integrative determinant of the phytoplankton community response to nutrient improvement. An increase in the phytoplankton biomass can be detected as an increase in the chlorophyll-a values (**Table 1**). Chlorophyll-a is a profit parameter of phytoplankton and algae biomass and is arguably the single most responsive indicator of N and P enrichment in the freshwater ecosystem [36].

Variables (indicators)	Threshold	Units	Trophic status
[24] TP	<7.9	µg/L	Oligotrophic
	8.0–11.0	µg/L	Oligotrophic to mesotrophic
	12.0–27.0	µg/L	Mesotrophic
	28.0–39.0	µg/L	Mesotrophic to eutrophic
	>40	µg/L	Eutrophic
Chl-a	<2.0	µg/L	Oligotrophic
	2.1–2.9	µg/L	Oligotrophic to mesotrophic
	3.0–6.9	µg/L	Mesotrophic
	7.0–9.9	µg/L	Mesotrophic to eutrophic
	>10	µg/L	Eutrophic

Variables (indicators)	Threshold	Units	Trophic status
[27] SD	>4.5	m	Oligotrophic
	4.5–3.8	m	Oligotrophic to mesotrophic
	3.7–2.4	m	Mesotrophic
	2.3–1.8	m	Mesotrophic to eutrophic
	<1.7	m	Eutrophic
TP	<10	µg/L	Oligotrophic
	10–35	µg/L	Mesotrophic
Chl-a	35–100	µg/L	Eutrophic
	<2.5	µg/L	Oligotrophic
	2.5–8.0	µg/L	Mesotrophic
	8.0–25	µg/L	Eutrophic
[5] DIN	<6.5	µM	(Good) Oligotrophic
	6.5–9.0	µM	(Fair) Mesotrophic
	9.0–16.0	µM	(Poor) Mesotrophic to eutrophic
	>16.0	µM	(Bad) Eutrophic
	<0.5	µM	(Good) Oligotrophic
DIP	0.5–0.7	µM	(Fair) Mesotrophic
	0.7–1.1	µM	(Poor) Mesotrophic to eutrophic
	>1.1	µM	(Bad) Eutrophic

TP: total phosphorus; Chl-a: chlorophyll-a; SD: Secchi disk; DIN: dissolved inorganic nitrogen; DIP: dissolved inorganic phosphorus.

Table 1. Some indicators for evaluating trophic status based on physical, chemical, and biological parameters.

Generally, two kinds of indices can be recognized. Indices are based on trophic levels of each species. To construct them, the abundance of each species in lakes with different nutrient levels is estimated by taking a trophic score, and in some cases, an indicator value into account [43]. These indices are based on the consideration that along with a gradient in nutrient concentration, each status can be identified by a specific structure of algal community [44].

All these indices are based on data from a number of lakes belonging to a relatively homogenized habitat in order to minimize the effects of biogeographic and climatic properties. These data are used to evaluate the trophic levels and the indicator values of the species, either by weighted averages [45] or using the lake score in a constrained ordination, considering the gradient in nutrient concentrations as the interpretive variable [43].

Diversity and similarity indices are an approach to estimate biological quality through the structure of the community. Diversity indices estimate the data on abundance within species in a population. The frequency of each species present in the fixed samples is determined according to relative units: (1) occasional, (2) rare, (3) frequent and (4) dominance. Different indices are used to estimate the community structure:

1. Hurlbert's probability of interspecific encounters (PIE) [46]:

$$PIE = \left(\frac{N}{N-1} \right) \left(1 - \sum_{i=1}^s p_i^2 \right)$$

N = the number of individuals in a community,

p_i = the fraction of a sample of individuals belonging to species i ;

2. Margalef's species richness [47]:

$$D = \frac{S-1}{\ln N}$$

S = the number of species in a sample,

N = the number of individuals in a community;

3. Menhinick's diversity [48]:

$$D = \frac{S}{\sqrt{N}}$$

S = the number of species in a sample,

N = the number of individuals in a community;

4. Shannon–Wiener diversity index [49, 50]:

$$H' = - \sum_{i=1}^s \frac{n_i}{n} \ln \frac{n_i}{n}$$

N = the number of individuals in a sample from a population,

n_i = the number of individuals in species i from a population;

As shown in **Table 2**, three classes of water quality were defined for the Shannon–Weaver diversity index by [51], who implied that a high H' value suggested a rich diversity and

therefore a healthier ecosystem (less pollution), whereas a low H' value suggested poor diversity and thus a less healthy ecosystem (more pollution).

Shannon–Weaver	Class	Condition
>3	I	Clean water quality
1–3	II	Moderate pollution
<1	II	High pollution

Table 2. The water quality classes determined for the Shannon–Weaver diversity index.

5. Pielou’s evenness index: The evenness of a community can be represented by Pielou’s evenness index [52]:

$$J' = \frac{H'}{H'_{max}}$$

H' is the number derived from the Shannon diversity index and

H'_{max} is the maximum value of H'

J' is constrained between 0 and 1. The less variation in communities between the species, J' is higher.

6. Simpson’s diversity index [53]:

$$D = \sum_{i=1}^s \frac{n_i(n_i - 1)}{n(n - 1)}$$

n = the number of individuals in a sample from a population,

n_i = the number of individuals in species i from a population

7. McNaughton’s dominance index [54]:

$$I = \frac{n_1 + n_2}{N} \times 100$$

N = the number of individuals in a community,

n_1, n_2 = the number of individuals of the two most dominant species in the sample;

8. Algal genus/species pollution index [55], as shown in **Table 3**. The index factors of the algae present are then summed. The top 20 algal species are rated on a scale from 1 to 6 (intolerant to tolerant), and the index is simply calculated by summing up the scores of all related species

present within the sample. Pollution scores of >20 means high organic pollution, scores between 15 and 19 mean probable evidence of organic pollution, and scores of <15 mean no or very low organic pollution and lack of nutrient enrichment.

Algal pollution index	Condition
≤14	Low organic pollution
15–19	Moderate organic pollution
≥20	High organic pollution

Table 3. Algal pollution index assesses the tolerance of algal species to organic pollution and for rating water quality.

9. Jaccard’s similarity index is a measure of the similarity between two samples [56]:

$$J = \frac{A}{A + B + C}$$

A = the number of data points shared between the two samples and

B and C = the data points found only in the first and second samples, respectively.

10. Saprobic index (S) [9]:

$$S = \frac{\sum(rh)}{\sum(h)}$$

r = the taxon saprobic rating (1 = oligosaprobic organism, 2 = β-mesosaprobic organism, and 3 = α-mesosaprobic organism),

h = the taxon occurrence rating (1 = occurring incidentally with <100 cells ml⁻¹, 2 = occurring frequently with 100–200 cells ml⁻¹, and 3 = occurring abundantly with >200 cells ml⁻¹; **Table 4**).

Saprobic index	Class	Condition
1–1.5	I	Very slightly contamination
1.5–2.5	II	Moderate contamination
2.5–3.5	II	High contamination
3.5–4	IV	Very high contamination

Table 4. Water quality classes according to saprobic index.

11. Carlson’s Trophic State index (TSI) [57]:

Eutrophication is the situation by which lakes are enriched with N, P, and organic compounds, increasing the production of rooted aquatic plants and algae. This is a condition demonstrating a lake’s trophic level. This is a measure of the trophic classification of a lake by using several analysis of water quality including: transparency or turbidity (Secchi disk depth), chlorophyll-a values (algal biomass), and total phosphorus concentrations. The TSI ranges from 0 to 100. Oligotrophy is between 0 and 30 TSI, where water is very clear, phosphorus is low, and algae are sparse. Thirty to fifty is a level showing increased in algae due to more available phosphorus (Table 5). If the TSI is more than 50, it describes a hypereutrophic habitat. In the Ref. [58] was detected water quality of Akgöl Lagoon was detected as mesotrophic level due to Trophic State index.

TSI	Chl-a (µgL ⁻¹) (surface)	SD	TP (µgL ⁻¹)	Trophic class/water quality
<30	<0.95	>26.2	<6	<i>Oligotrophy</i> , clean water, oxygen throughout the year at the bottom of the lake
30–40	0.95–2.6	13.1–26.2	6–12	Bottom of shallower lakes may become anoxic
40–50	2.6–7.3	6.6–13.1	12–24	<i>Mesotrophy</i> , water moderately clear most of the summer
50–60	7.3–20	3.3–6.1	24–48	<i>Eutrophy</i> , algae and aquatic plant problems possible
60–70	20–56	1.6–3.3	48–96	Cyanobacteria dominate, algal scums and aquatic plant problems
70–80	56–155	0.8–1.6	96–192	<i>Hypereutrophy</i> , dense algae and macrophytes, light limited
>80	>155	<0.8	192–384	Algal scums, few aquatic plants

TP: total phosphorus; Chl-a: chlorophyll-a; SD: Secchi disk.

Table 5. Water quality classes according to Trophic State index (TSI).

12. Species number; species number as a simple measure of species richness, in spite of its simplicity, was reported to be a good tool for eutrophication appraisalment in the freshwater ecosystem.

13. A similarity index was calculated by using the Euclidean distance algorithm. Two kinds of matrices were used: one considering only species presence–absence data and the other considering both presence–absence and abundance data.

6. Case studies on relationship between algae composition and water quality

The objectives of these studies were: (1) to recognize freshwater properties (physiological, population and community structure) that consistently change along with water quality gradients, and to quantify their direction and size of responses; (2) to recognize the water

quality variables that best prognosticate alters in these prospects; (3) to isolate and calibrate a final set of bioindicators, based on their consistency of response across regions and with due consideration of the practicality of their measurement, which can be monitored as a proxy of water quality in places where direct water quality analyses are not available.

According to the Ref. [59], blooms of *Anabaena circinalis*, *A. spiroides*, and *Aphanizomenon flos-aquae* of filamentous *Cyanobacteria* were coincided with a decrease of the zooplankton abundance in the Yeniçağa Lake. It may be assumed that the appearance of inedible filamentous cyanobacteria results from the eutrophication of the lake, and so there is evidence concerning the eutrophication steps.

Lake trophic condition is typically evaluated by monthly sampling of some kinds of physical and chemical indicators. If changes in species diversity and population abundance occur from either direct or indirect ecological stressors, then changes in biota may be used to assess descriptive alters in the ecosystem. The altitude of lakes will affect the algal diversity depending on oxygen saturation changes. Increases in growth rate and the algal diversity at high altitude lakes will indicate that they can be safe and productive water sources for the future time. The Ref. [60] investigated that the physicochemical properties and planktonic composition of the lakes showed that there was a fast tendency towards 'eutrophism' especially Mogan and Abant lakes. The temporal and spatial variables of situations affecting structure of the plankton composition appeared in the two lakes which were mainly resulting from pre-eutrophication. The Ref. [61] pointed out clearly that water quality monitoring was based on algal community structure. Especially, the improvement of diatom-based pollution indices has become a significant part of water quality monitoring in Turkey.

Furthermore, Refs. [62–64] have indicated that certain indices for the appraisalment of eutrophication states in aquatic habitats are not as highly developed as in freshwater ecosystems and are not clearly defined. Plankton size structure can be used as a common taxon-independent tool for the study of community and ecosystem structure in aquatic habitats, in order to evaluate energy flows, biomass and abundance appropriation among different size fractions or different size classes in continuous size range. It is widely indicated that morphometric size has significant implications for the physiology and ecology of species through underlying dynamics that identify specific body size due to metabolic rates and ecological regulation of organism density, which in turn affect coexistence mechanisms.

Due to multiple species forming communities, certain adaptations are shown to limiting environmental factors and biochemical tolerance limitation of individuals of different species in the community constitute such type adaptation. At the other side, there might be species that are each limited by different nutrients (homogenized habitat) [65]. Thus, limitation at the community level is probably dependent upon a combination of mechanisms, from those that cause species to be similarly limited by the same nutrients, and to niche specialization mechanisms that cause species to be differently limited by different nutrients. Due to the effect of ecological factors, these species are considered as indicator species in the habitat according to their tolerance limits. According to Ref. [22], managing an aquatic ecosystem consistent with the ecological requirements of a specific bioindicator may fail to protect rare species with different necessities.

7. Conclusion

Algal communities react rapidly to disturbance of water, for example physicochemical conditions of water or to pollution-affected catchment area. They frequently change their species composition or diversity, which can vary from species-rich to monotonous communities. Because of this characteristic, benthic diatom communities are useful tools in detecting anthropogenic impacts.

The qualitative samples and community measurements of algae are beneficial in order to monitor the aquatic ecosystems. Majority of the interannual differences in temporal dynamics of algae, from oligotrophic to hyper-eutrophic lakes, can be caused by ecological factors, morphometry and climate. There are modest interannual variations that may affect the numbers, relative abundance and occasional dominance variation of the algae in consecutive years. In conclusion, algae are increasingly used to monitor the ecological quality and health of the aquatic ecosystem and also to define the effectiveness of management or restoration programs, or regulatory actions.

Consequently, the total objective of bioindicators is to use a single species, or a specific community to evaluate the quality of an ecosystem and how it alters with time, but this can represent a gross more vulgarization of a complex system. As is in all water management implementation, we must be conscious of its defects. On the other side, the limits of bioindicators are apparently minimized by their advantages. Bioindicators can be employed at a range of scales, from the microhabitat to the ecosystem level, to assess the health of a characteristic ecosystem. They bring together information from the biological and physicochemical structure of all aquatic ecosystems as is in changes of population density, community structure and ecosystem processes. Bioindicator is valuable to reflect biological sustainable concept for water management.

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